Organization: University of Pennsylvania

Title: Modeling Complex Interactions in Microfluidic Systems

MTO Simbiosys

Start Date: July 2001 **End Date:** July 2004

Principal Investigator(s): Haim H. Bau
Phone: (215) 898-8363 Email: bau@seas.upenn.edu
Web: http://www.seas.upenn.edu/meam/faculty/bau.html

Agent: Tom Mautner SPAWAR (619) 553-1621 mautner@spawar.navy.mil

Project Goals

We study theoretically and experimentally complex flow phenomena and biological interactions in microfluidic systems. Specifically, we focus on the transport of liquids and particles in micro-conduits and their effect on biological interactions; the modeling of electrokinetic flows; and the use of magnetic and electrostatic forces to manipulate particles and to stir and pump fluids. Among other things, we will develop magnetohydrodynamic and electrokinetic stirrers.

Technical Approach

We will construct mathematical models, implement the models in computer codes, conduct parametric and optimization studies, and reduce the results to concise, easy to use design rules and formulas. In order to verify the theoretical predictions, we will carry out experiments and critically compare the experimental observations with predictions. The microfluidic systems needed for the experimental verifications will be fabricated with low temperature, co-fired ceramic tapes (LTCC). LTCC allow us to fabricate devices and systems rapidly and inexpensively; we can literally go from a design to a prototype in a matter of days. The reaction rates, as well as the effects of flow conditions and the presence of particles on the reaction rates will be measured in a BIACORE optical biosensor.

Recent Accomplishments

- Two prototypes of magneto hydrodynamic (MHD) stirrers that exhibit chaotic behavior were designed and modeled. One stirrer consists of a closed cavity while the other is an open conduit. The theoretical predictions were compared with experimental observations.
- The concept of a magneto hydrodynamic (MHD) fluidic network was developed. The network consists of many individually controlled branches that can double-up as "pumps" and "chaotic stirrers." By appropriate control of the potential differences (or currents) applied to different branches, liquid can be directed to follow any desired path without a need for mechanical valves and pumps. Linear networks-based theory was developed to facilitate the control of the network. A simple prototype was fabricated with low temperature, co-fired ceramic tapes to demonstrate the basic concept.
- Theoretical calculations were carried out to demonstrate the feasibility of constructing electroosmotic stirrers that exhibit chaotic advection.
- The computer program "Particle Mover" was modified to study the motion of spherical particles in conduits with rectangular and triangular cross-sections. The existence of an equilibrium position for the particles was demonstrated.
- Simple closed-form expressions were derived to model the biological interactions between analyte in solution and wall-bound liegand under conditions in which convection and diffusion cannot be neglected.

Sixth-Month Milestones

- We will study the motion of multiple spherical particles in conduits with rectangular and triangular cross-sections and model the motion of cylindrical particles in narrow tubes.
- The capabilities of the "Particle Mover" will be extended to include electric fields.
- Experiments will be carried out to obtain data on biological interactions. This data will be used to verify theoretical predictions. A model will be developed to account for volumetric biological interactions in a "porous" medium.
- Purified soluble recombinant proteins IL5R will be produced for biosensor-based flow interaction analysis.

Team Member Organizations

N/A

University of Pennsylvania

A MAGNETO HYDRODYNAMIC FLUIDIC CIRCUIT

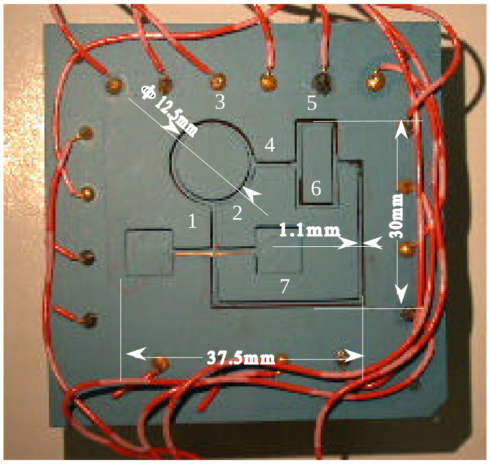

***Fig. 1**: A photograph of the MHD fluidic network. The dimensions (mm) of the various features are given in the photograph. The circuit consists of individual branches, each equipped with a pair of individually controlled electrodes aligned along the conduit's side walls (see Fig. 2). The device is positioned in a uniform magnetic field. Some of the branches may also be equipped with centrally located point electrodes. These branches can double-up as "pumps" and stirrers. By judicious application of potential differences to various electrode pairs, one can direct the fluid to follow any desired path without a need for mechanical pumps and valves. For example, the liquid was forced to circulate a few times around the "torus" 2-3. Then it was pumped into branch 4 and split at desired proportions between branches 5 and 6. Some of the problems associated with electrode corrosion, bubble formation, and charged particles' migration can be alleviated through the use of alternating, synchronized electric and magnetic fields. The device operates at relatively low voltages.*

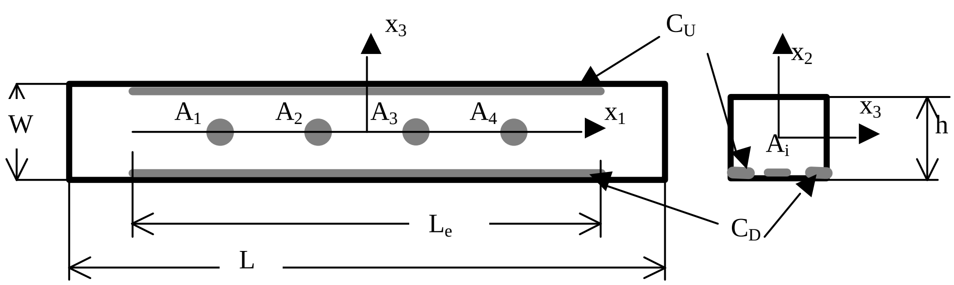

***Fig. 2**: The basic building block (branch) of the microfluidic network (top view, left, and cross-section, right). The figure is <u>not</u> drawn to scale. When the branch is operating in a pumping mode, the potential difference is applied across electrodes C_U and C_D. When operating in a stirring mode, electrodes C_U and C_D are interconnected to form a single electrode (C), and the potential difference alternates among electrode pairs C-Ai.*

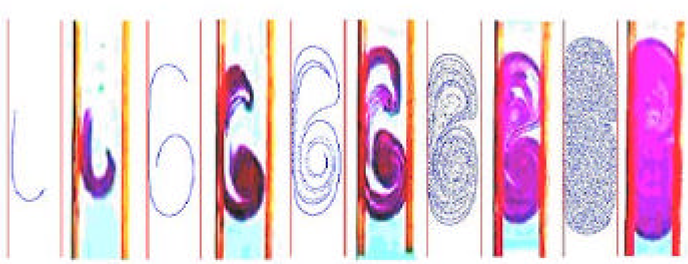

***Fig. 3**: The network branch doubles as a stirrer. The potential difference alternates periodically between electrode pairs A_2-C and A_3-C (see Fig. 2). The alternations in the flow field result in chaotic advection. The figure compares theoretical predictions with flow visualization experiments.*